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July 1962

Quarterly Memorandum No. 3

"MULTIMEGAWATT BROADBAND MICROWAVE TUBES"

M. L. Report No. 933

TECHNICAL NOTE
for
CONTRACT AF 30(602)-2575
Project No. 5573
Task No. 557303

Microwave Laboratory
W. W. Hansen Laboratories of Physics
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Stanford, California

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ABSTRACT

1. Long Slot TWT

The work this quarter was concerned with the measurement of insertion loss due to a radiating slot in the wall of the cavity. It was found that a minor misalignment of the cavities can cause drastic changes in the transmitted power as well as in the reflection at the couplers.

2. Ten Megawatt Cloverleaf TWT

The efforts on this project have been reduced, pending the modification of the existing amplifier. The modification includes replacing the electron gun with one adaptable to beam focusing of the convergent confined flow type.

3. Tapered Structures

The final report on this project is in preparation.

4. Centipede TWT

A major part of the effort this quarter was directed toward a leaky wall structure for loop mode suppression in the range of observed backward wave oscillations of the experimental TWT amplifier.

The other major concern of this project was with the examination of certain data which appeared in the previous report, data about coupled mode analysis of a structure consisting of a periodic circuit coupled to a dielectrically-loaded waveguide.

5. Electron Stick

A new model of the electron stick has been completed; procedures for the forthcoming tests are described.

6. Hollow Beam Guns

The range of a solution to the equations of space-charge limited flow is determined mainly by the position of the critical points in the complex plane of the cathode. No solution exists around such points, and it is desired that cases be found where these singularities are either far removed or do not exist. The work done in the study of cathode shapes in which such singularities do not exist is described.

7. Extended Interaction Klystrons

Further work on the theory of the stub-supported meander (SSM) line has rendered its dispersion and impedance closely predictable. Performance with a cylindrical beam promises to be nearly the same as that of the centipede circuit, but in addition, the Pierce impedance at the planar circuit is insensitive to velocity scaling. At present, the use of resonant sections of SSM line as cavities for an extended-interaction klystron is being studied.

8. Non-Periodic Dielectric-Lined High-Power TWT

The work on this project is presently deferred, pending the outcome of the tests on the Electron Stick project.

INTRODUCTION

This is Quarterly Memorandum number three for this contract, for the period of 1 March to 31 May 1962. At the present time there are eight projects active under this contract:

1. Long-Slot TWT
2. Ten Megawatt Cloverleaf TWT
3. Tapered Structures
4. Centipede TWT
5. Electron Stick
6. Hollow Beam Guns
7. Extended-Interaction Klystrons
8. Nonperiodic Dielectric-Lined High-Power TWT

The project formerly titled "Periodic Circuit Measurement Techniques" is now complete and a Technical Note has been written and submitted for approval, by M. I. Carswell, titled "Experimental Investigations of Transmission Line Representations of Microwave Periodic Circuits," M. L. No. 915, Microwave Laboratory, Stanford, California (April 1962).

This contract extends the work previously done under RADC Contract AF 30(602)-1844 (and reported in various reports under that contract), and also provides support for certain additional studies of tube components and related matters.

The Responsible Investigator for this contract is Professor Marvin Chodorow.

I. OBJECTIVE OF THE CONTRACT

The general overall objective of this contract is to conduct theoretical and experimental investigations of microwave tubes with a view toward the development of tubes capable of at least 10 megawatts of peak power, average power approaching 50 kilowatts, bandwidths approaching 30 per cent, gains of 35 db, and efficiencies of 40 per cent.

II. SUMMARY AND ANALYSIS OF THE WORK

A. LONG-SLOT TWT (R. A. Craig,* C. C. Lo)

1. Objective

The objective of this project has been to investigate a circuit which is theoretically capable of giving larger bandwidths than any megawatt tube yet tested, perhaps at high as 20 per cent, and to improve its performance and stability characteristics. This circuit uses coupled cavities in which the coupling is done through circumferential slots resonant at a lower frequency than the cavity resonance.

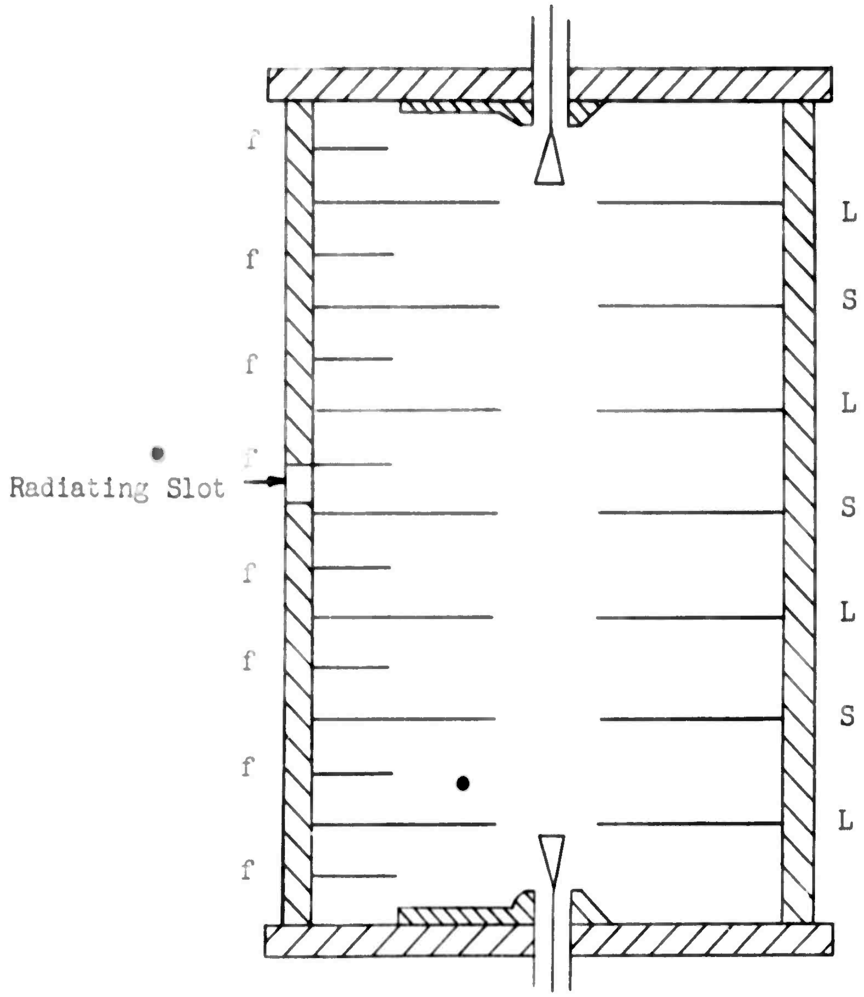
2. Present Status

The efforts during this quarter on the long slot TWT were directed toward the measurement of insertion loss due to a radiating slot in the wall of the cavity. In order to accomplish this task a suitable coupler was designed which matched the slow wave structure in the upper TM_{02} waveguide mode. An adequate match was finally achieved by means of suitably designed E-field probes at each end of a slow wave structure consisting of alternately spaced long and short slot cavities. A low VSWR was obtained over a frequency range of 4980 Mc/s to 5070 Mc/s. As will be recalled from previous reports, the long- and short-slot cavities have almost identical fundamental passbands, but may have different upper passbands. Since the first long-slot, coupled-cavity traveling-wave tube was assembled from both long and short slots, it was felt that the attenuation measurements should be made with a similar structure.

*Project supervisor

The test section consisted of six cavities of this type matched at each end by these suitably designed probes. The VSWR at each probe was less than 2 to 1, over most of this frequency band. Figure 1 shows a schematic drawing of the test cavity and the location of the radiating slot in the structure. Preliminary measurements made on a cylindrical resonant cavity indicated that the frequency perturbation of such a slot was considerable, but it was felt that the cavity Q might be lowered sufficiently by the slot to minimize the effects of detuning insofar as coupling to adjacent cavities is concerned. The radiating slot was cut in the central cavity of the structure and located with respect to the perturbing fingers and coupling slots as shown in Fig. 2. The radiating slot was 1-1/4 in. long by 1/8 in. wide. The slotted cavity was inserted in the test structure as shown in Fig. 1. The VSWR for the entire frequency range, which was less than 2:1 when there was no slot present, increased and reached a value of 3.4 to 1. When the window was loaded with absorbing material which had a dielectric constant of a approximately 1.4 and a loss tangent of approximately 0.06, the VSWR decreased to between 2 and 3 to 1.

The power transmitted through the test structure was measured for three different cases: (1) with no radiating slot, (2) with slot in the position indicated in Fig. 2 which was radiating into free space, and (3) when the slot was loaded with the absorbing pads of lossy material. The insertion loss through the structure without the radiating slot had an average value of about 3.5 db over the aforementioned frequency band. This was much higher than one would expect from theoretical calculation based on the group velocity and the Q of the unloaded circuit. It was felt therefore, that some loss was occurring in the two end cavities which were loaded heavily with slugs of metal to match the probes to the rest of the slow wave circuit. However, the measurements were continued in an effort to obtain some data. It was found that an increase in the attenuation through the structure of about 2 db was obtained when the radiating slot with loss over it was added, and this increased to almost 5 db when the slot was allowed to radiate into free space. These values of loss seem extremely high for one radiating slot, even when the reflection due to the higher VSWR looking into the structure is taken into consideration. Thus, it is apparent that the slot perturbs the resonant frequency of the



f - finger ring

L - long slot plate

S - short slot plate

FIG. 1--Schematic of the experimental section used to measure loss due to resonant slot.

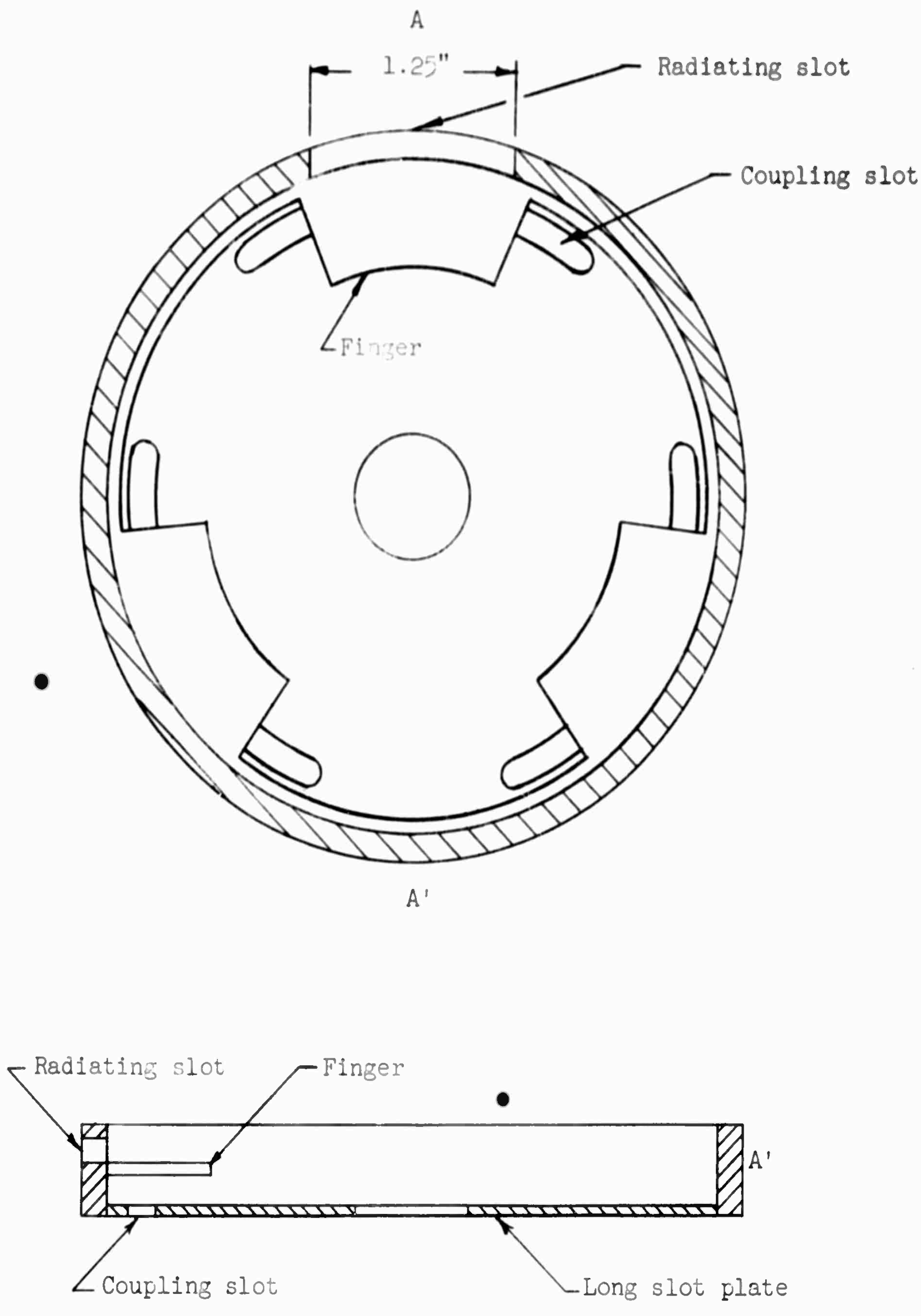


FIG. 2-- Location of radiating slot for maximum attenuation.

one cavity too much and this detuned cavity is highly reflective, which results in the high insertion loss. This in addition to the high residual insertion loss (no slot present) means that the measurements are probably in considerable error. When the test section was dismantled it was found that some of the tuning slugs in the cavity had become loosened and it is likely that this results in excessive attenuation in the coupler cavity itself. Therefore, efforts will be made during the next period to correct this situation and to obtain more realistic data before proceeding with construction of the amplifier.

It was found during the course of these measurements that a minor misalignment of the cavities can cause drastic changes in the transmitted power as well as in the reflection at the couplers. The misalignment was rotational so that the coupling slots were slightly rotated with respect to each other. Previous studies have shown that this rotation does not cause any appreciable effect in the fundamental passband which is used for amplification. However, no tests have been made of the upper passband until recently. This may explain why an oscillation occurred in the upper passband which was relatively fixed in frequency regardless of the beam voltage on the original amplifier. It is believed that a better alignment technique must be used in the tube fabrication if one is to eliminate any reflection in the upper passband due to this rotation. While misalignment in the first amplifier may have been the cause of the upper passband oscillation it is felt that other precautions, such as the addition of attenuation by means of a radiating slot, should be included in the amplifier design in order to be sure of reducing the possibility of oscillation in this upper passband to a minimum.

During the next interval, tests of attenuation through the slow wave circuit with radiating slots in every cavity will be made. Attenuation will be measured in both the upper and the fundamental passband. Then a suitable method of absorbing the radiated power will be devised and the construction of an amplifier begun. Barring unforeseen difficulties, the amplifier should be completed by the end of the next quarter and preliminary hot test data obtained.

B. TEN MEGAWATT CLOVERLEAF TWT (R. A. Craig)

1. Objective

The objective of this project was to develop a cloverleaf TWT with 10 megawatts peak power, a TWT with as high efficiency as possible and as much bandwidth that can be obtained in a cloverleaf circuit.

2. Present Status

An electron gun, which is adaptable to beam focusing of the convergent confined flow type, has been ordered. It will be used to replace the gun now in use which provides a Brillouin focused electron beam. Present plans are to make this modification and take measurements suitable for direct comparison with those previously taken on the amplifier.

C. TAPERED STRUCTURES (R. A. Craig,* C. C. Lo)

1. Objective

The objectives of this project are to demonstrate that the pulse edge oscillation problem in high-power TWT amplifiers can be reduced or eliminated completely by the use of a tapered output section. It is to be understood that the other uniform sections would be designed with low enough gains so that pulse edge oscillations would not exist in the sections and be transmitted to the output by the modulated electron beam.

2. Present Status

The final report on a high-power TWT amplifier employing a tapered, cloverleaf circuit designed to suppress pulse-edge oscillations is in preparation. This program is presently inactive pending completion of the electron stick.

D. CENTIPEDE TWT (D. K. Winslow,* F. Ivanek, A. Bahr)

1. Objective

The centipede structure has given, to date, the most all-around satisfactory circuit performance for a high-power traveling-wave tube. The objectives of the present study are (1) to suppress the observed oscillations in the higher frequency loop passband and also the pulse-edge oscillations at the π-mode of the operating band without incorporating excessive attenuation in the frequency range of operating, and (2) to improve

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*Project Supervisors

the overall circuit performance. The first objective is being pursued using two alternative approaches: coupling of the unwanted modes into a heavily attenuated external region or waveguide by means of resonant slots, and selective mode coupling of the undesired modes to an external lossless uniform guide. The techniques used here could be adapted to other types of circuits, such as the "cloverleaf" or the "long-slot." The study directed toward the second objective, i.e., improved circuit performance, has a somewhat wider scope in that it also makes use of the existing knowledge of related structures and indicates the possibility of building new types of circuits.

2. Present Status

The current work is reported in two parts. Part I presents the investigation of coupling of undesired modes into an external attenuated region or into a waveguide which has the waveguide cutoff frequency above the operating frequency range of the tube. The improvement of overall circuit performance is also included in this section. Part II has objectives similar to those of Part I and considers a similar method of coupling. The essential difference is that the external waveguide is coupled to the structure throughout the operating frequency range of the tube as well as the frequency ranges in which instabilities are observed. Attenuation of the undesired frequency ranges, with negligible attenuation in the operating band, is accomplished here by properly adjusting the phase and attenuation characteristics of the external circuit.

Part I

The major efforts during this period were directed toward a leaky wall structure for loop mode suppression in the range of observed backward wave oscillations of the experimental TWT amplifier.[1]

The leaky wall scheme uses slots in the cylindrical wall of the structure, such that their resonance falls within the frequency range where loop mode suppression is wanted. On the outside of the structure the slots can be terminated either by a lossy dielectric which acts as an absorber, or by

[1] "The Centipede High-Power Traveling-Wave Tube," Microwave Laboratory Report No. 695, Stanford University, sec. 4, p. 7 (May 1960).

waveguides partially filled with some efficient absorber. The former solution was adopted in the reported experiments, but a preliminary investigation of the latter was also undertaken.

A 16 section leaky wall structure was built with four symmetrically arranged slots per section which connect the outer loop region with the external absorber (3/4 inch layer of Eccosorb LS 22). The performance of this scheme was tested by the measurements of transmission loss it introduces. Distributed loss was introduced initially by spraying the section with kanthal in order to achieve better matching of the coax-to-centipede couplers used at both ends of the structure. A VSWR of better than 2:1 was obtained over the entire lower half of the loop passband. The slot resonance was placed near the center of the matched frequency range, where the backward wave oscillations were observed. The maximum measured attenuation was 2.5 db per section at slot resonance. Approximately 0.75 db attenuation per section was considered as sufficient to suppress the loop passband oscillation.[1] This is obtained in the present leaky wall structure over a frequency range of 800 Mc/s at the lower end of the 4300 - 6400 Mc/s loop passband.

The effect of the leaky wall scheme on the operating TM_{01} passband was investigated using plain sections, without kanthal spraying. The dispersion characteristic and relative interaction impedance are affected by a negligible amount. The attenuation, as computed from measured values of a resonant 8-section structure, showed on the average a six-fold increase over the unslotted structure. The actual amount of attenuation is, however, negligible since it averages about 0.15 db per section within the 2570 - 3225 Mc/s range lying between $\beta L = \pi/4$ and $\beta L = 3\pi/4$, which corresponds closely to the passband that could be exploited in a TWT amplifier using the structure under consideration.

Work is continuing on the leaky wall scheme with the objective of suppressing also the TM_{01} mode at the upper limit of the operating passband where pulse-edge oscillations were observed.[1]

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[1] "The Centipede High-Power Traveling-Wave Tube," Microwave Laboratory Report No. 695, Stanford University, sec. 4, p. 7 (May 1960).

Part II

The work on this part of the project during this period was directed toward the examination of certain details which appear in the previously reported coupled-mode analysis[1] of a structure consisting of a periodic circuit coupled to a dielectrically-loaded waveguide. The theory shows that by using such a coupling scheme it should be possible to couple out the various backward waves and reflections which produce oscillations when the periodic circuit is used in a high-power traveling-wave tube. Moreover, this can be done without greatly affecting the forward gain in the amplifier operating band.

The periodic structure that will be used in an experimental test of this theory is the centipede structure. Coupling between the centipede and the external waveguide is obtained by providing a coupling slot between each of a number of centipede cavities and the waveguide. One is required to know the magnitude and frequency dependence of the coupling that can be provided by one such slot; this must be determined experimentally. By one-slot coupling we mean the fraction of forward power in the driven guide that is coupled forward in the undriven guide by one slot.

To measure this coupling, a number of sections of periodic structures can be resonated and coupled to the external waveguide through one slot. One arm of the waveguide is perfectly terminated and the other is provided with a sliding short. The difference between the loaded Q's of the resonant system when there is maximum coupling and zero coupling through the slot will give a measure of the coupling. By considering the relation between stored energy and power flow in a passband and by taking into account the standing-wave nature of the fields, one can derive the following expressions for coupling:

$$\text{Coupling} \overset{\Delta}{=} K^2 = \frac{\omega_0 LN}{8\, v_g \cos^2 \beta_0 z} \left(\underset{\substack{(\text{max.}\\ \text{coupling})}}{\frac{1}{Q_L}} - \underset{\substack{(\text{no}\\ \text{coupling})}}{\frac{1}{Q_L}} \right) , \qquad (1)$$

[1] Quarterly Memorandum No. 2 for Contract AF 30(602)-2575, Microwave Laboratory Report No. 903, Stanford University, (March 1962), pp. 9-21.

where

ω_0 = resonant frequency (radius)

L = period of structure

N = number of resonant sections

v_g = group velocity of the operating mode

β_0 = fundamental phase constant of the operating passband

z = position of the slot relative to one shorted end of the resonated structure.

Q_L = loaded Q .

We note that Eq. (1) is only meaningful in a passband where v_g is defined and not equal to zero. Also no coupling will be observed if the slot is located at a standing wave null. Moving the slot or changing N will avoid this difficulty.

A preliminary measurement was made using an S-band waveguide in order to establish the measurement techniques. It was found that one should have enough sections so that moving the slot one section to either side of the middle of the cavity will not have significant effects due to the proximity with the shorted ends of the cavity. Also, one should operate well below the resonant frequency of the slot because otherwise the fields in the passband are perturbed and the coupling measurements are unreliable.

Using a 1.34 in. slot, the coupling in the passband was found to be an order of magnitude smaller than that desired (as determined by the desired coupling length) and was found not to vary too greatly with frequency. These measurements are encouraging since constancy of coupling is desirable and since we expect the coupling to increase when we use a dielectric-loaded waveguide.

Also during this period the question of the validity of using continuous coupling and neglecting reflected waves in the coupled-mode analysis was examined. Since there is a definite phase relation between waves generated from successive coupling holes it might be thought that the reflected waves would not cancel except when the phase-shift per section was near $\pi/2$.

To check this, the transfer of power between two periodically-coupled identical transmission lines was calculated using scattering-matrix techniques and a computer. All four possible waves were included. The result was that negligible power is coupled into the reflected waves for phase shifts per section in the ranges $\pi/8$ to [illegible]$\pi/8$, [illegible]$\pi/8$ to 1[illegible]$\pi/8$, etc., with minima occurring at $\pi/2$, [illegible]$\pi/2$, etc. At 0, π, etc., large amounts of power are reflected in the driven guide. We may think of these coupled transmission lines as a model for our periodic structure coupled to an external waveguide (in a passband). The periodic structure looks like a uniform transmission line to the external waveguide because the fields in the structure are only sampled by the waveguide once in each period. The addition of a beam will not tend to generate reflected waves. Hence, the neglect of reflected waves in the range of phase shifts quoted above is a valid assumption of the coupled mode analysis.

As has been emphasized repeatedly, all the theory on the effect of coupling an external waveguide to a TWT that has been described so far in these reports is only good in the structure passband. However, the oscillations we are interested in occur near the π cutoff of the structure passband. What is needed, then, is a theory of the beam-circuit interaction at cutoff and in the stop-band that would be of such a form as to allow the effect of adding the external waveguide to be calculated in a simple manner. Further work will be directed toward the development of such a theory and to experimentally evaluate the proposed coupling schemes on the electron stick.

E. ELECTRON STICK (D. K. Winslow,* A. Bahr)

1. Objective

The electron stick has been developed to evaluate high-power tube circuits without the construction of a complete tube; it consists of an electron gun, collector, and a long glass tube shielded from the electron beam by a closely spaced tungsten helix. The helix prevents the charging of the glass and is essentially transparent to the rf developed by the circuits which are external to the glass vacuum envelope. Operating at a low duty cycle, nearly 100% beam transmission has been obtained at a peak power of 7 megawatts, 110 kv and 62 amperes. The objective is to adapt the electron stick to many of its possible uses, namely; to evaluate

*Project supervisor

the effectiveness of the externally coupled waveguides on the centipede circuit in order to eliminate backward wave oscillations; to test the dielectric loaded waveguide as a high-power traveling-wave tube; and to evaluate new circuits, the effects of tapering the circuit, and the effect on tube operation of changing many of the circuit and coupling characteristics. These operations may now be accomplished since the rf circuitry is outside the vacuum envelope.

2. Present Status

A new model of the electron stick has been completed and is ready for the high voltage dc beam test. The movable focusing coils, the positioning mechanism for both the coils and the rf structures, and all of the auxiliary equipment are assembled in operating position and ready for use. Calculations and measurements are being continued on the external helix attenuator on the electron stick in order to damp the observed oscillations.

The electron stick will now be operated at high voltage to check the alignment. Most of the present effort is being directed toward the assembly of the centipede structure which is to be mounted on the electron stick. The measurement of the rf characteristics of the structures under a variety of conditions (considered in detail in the centipede section of this report) will then proceed.

F. HOLLOW BEAM GUNS (K. J. Harker,* K. Dedrick)

1. Objective

The purpose of this project is to produce electron guns with high perveance and convergence. The most promising approaches to this problem are based on curvilinear flows instead of the more conventional rectilinear flows. For some time, the principal method of attack on the curvilinear flow problem has been that of experimental cut-and-try techniques. The goal here has been to reduce gun design for curvilinear flow to a more analytical and systematic scheme.

2. Present Status

As mentioned in previous reports, the range of a solution to the equations of space-charge limited flow is determined mainly by the position

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*Project supervisor

of the critical points in the complex plane of the cathode. No solution exists around such points, and it is important to seek cases where these singularities are either removed as far away as possible or they do not exist. We will now descirbe the work that has been done in the study of cathode shapes in which these singularities do not exist.

Such singularities only occur when the lone element

$$ds^2 = dx^2 + (r\, d\,\theta)^2 \tag{1}$$

vanishes somewhere in the complex plane of the cathode.

In Eq. (1), the line element has been expressed in spherical polar coordinates (r , θ , ϕ) and is evaluated along a meridan (ϕ = const.) taken on the surface of the cathode. It is our purpose to use Eq. (1) as the generator of cathode surfaces $r(\theta)$ for which the line element can not vanish.

Equation (1) can be written

$$\left(\frac{ds}{d\theta}\right)^2 = \left(\frac{dr}{d\theta}\right)^2 + r^2 \neq 0 \quad , \tag{2}$$

and the non-vanishing of Eq. (2) can be assured by writing

$$\left(\frac{dr}{d\theta}\right)^2 + r^2 = e^{f(\theta)} \quad . \tag{3}$$

The solutions to Eq. (3) for specific choices of $f(\theta)$ are then the cathode shapes $r(\theta)$ to be determined. For example, let $f(\theta) = 1$; then the solutions of Eq. (3) are $r = \pm 1$, and $r = \pm \cos(\theta + \alpha)$, where α is a constant. This example demonstrates that more than one solution can be expected, and it will always be necessary to exercise some caution in solving Eq. (3) so that all solutions are retained. We are specifically interested in solutions to Eq. (3) having the property that $(dr/d\theta)$ is zero when θ vanishes (this point is important in that it assures that the cathode will be smooth near the polar axis). This in turn requires that $f(\theta)$ be an even function.

The solution to Eq. (3) is written

$$r = a_0 + a^2\theta^2 + a_4\theta^4 + \ldots\ldots , \tag{4}$$

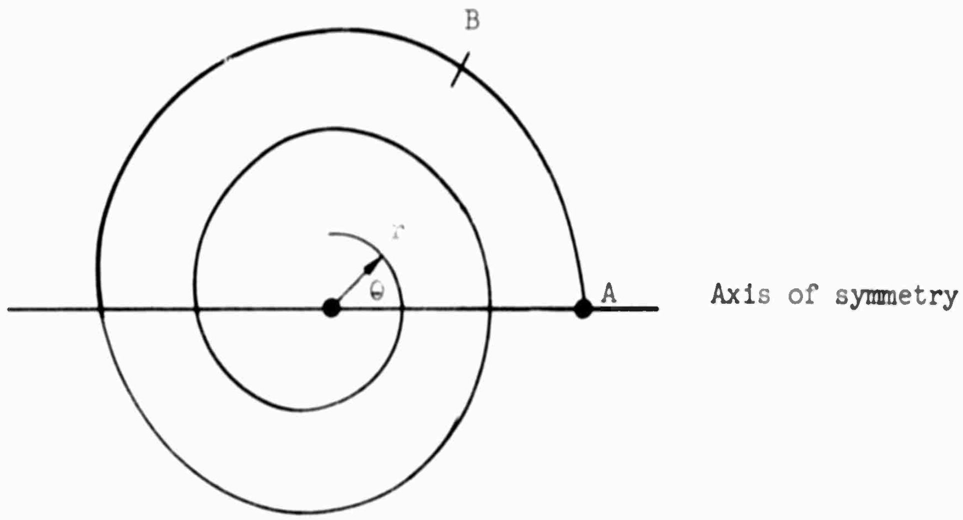

FIG. 3--Generators of possible cathode shapes.

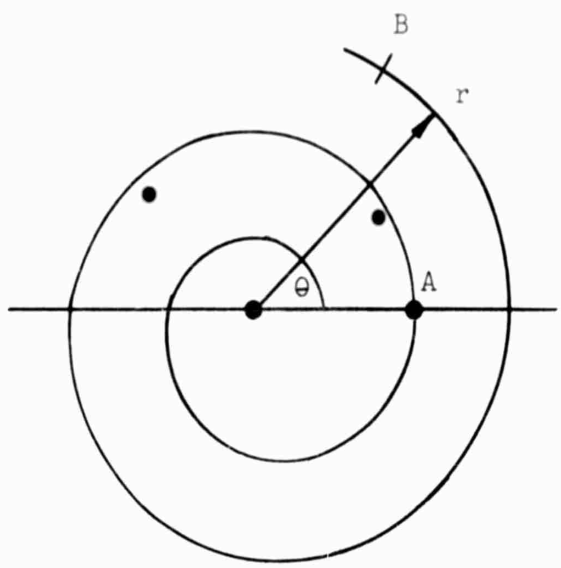

FIG. 4--Generators of possible cathode shapes.

where

$$f(\theta) = f_0 + f_2\theta^2 + f_4\theta^4 + \ldots \quad . \tag{5}$$

The coefficients a_0 , a_2 , a_4 are readily obtained by substitution in Eq. (3):

$$a_0^2 = e^{f_0} \tag{6a}$$

$$a_2 = (a_0/4) \left[- 1 \pm \sqrt{1 + 4 f_2} \right] \tag{6b}$$

$$a_4 = \frac{a_0}{2 (- 1 \pm \sqrt{1 + 4 f_2})} \left[(1/2) f_2^2 + f_4 - (1/8) - (1/4)f_2 \pm (1/8)\sqrt{1 + 4 f_2} \right] , \tag{6c}$$

etc.

It is clear that these solutions are valid for complex values of θ , and are useful as a check on solutions obtained by numerical methods.

Numerical solutions to Eq. (3) were obtained for various values of the f_i in Eq. (5). In general, helical shapes which wound inward and outward were obtained. Two sketches of some typical shapes are shown in Figs. 3 and 4. Possible useful portions of these shapes as cathode profiles would be the arcs between A and B.

G. EXTENDED-INTERACTION KLYSTRONS (M. Chodorow,* B. Kulke)

1. Objective

The objective of this project is the evaluation of the stub-supported meander line and related circuits for use in high-power extended-interaction klystrons (and/or traveling-wave tubes). Extended-interaction klystrons can have a larger gain-bandwidth product and greater efficiency than conventional klystrons. A planar structure, in conjunction with a strip beam, can in theory produce more efficient beam-circuit interaction than a cylindrical structure because more electric field becomes accessible to the beam.[1]

2. Present Status

Theoretical analysis of the stub-supported meander (SSM) line, as discussed in previous reports, has been based on characteristic admittances

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*Project supervisor

[1]M. Chodorow, T. Wessel-Berg: "A High-Efficiency Klystron with Distributed Interaction," Trans. IRE ED-8, 44-55 (Jan. 1961).

for the assumed transverse TEM waves which were derived from the assumption of constant electric field in the space between the bars. These admittances take the form of series expansions which have been tabulated for a number of circuit geometries;[1] thus they provide a simple reference from which to predict trends of dispersion and impedance. This theory, however, gave consistently low predictions of group velocity and stored energy.

Butcher[2] has derived a characteristic admittance for infinitely thin tapes in an open array, allowing for nonconstant fields between bars as well as for edge singularities. This model appears to represent a wide-spaced circuit such as the SSM line much more closely than Welling's model; a convenient tabulation of the Butcher admittances does not exist, however. For mathematical simplicity, the admittance corresponding to tape width equals gap width was used; this has resulted in the following improvements in the theoretical analysis of the SSM line:

(a) A better estimate of dispersion was obtained. Phase velocity is now predictable within less than five per cent over 80% of the cold passband, for stub lengths in the range of interest.

(b) An improved estimate of impedance was found. Pierce impedance at the circuit is now predictable within less than factor two over 80% of the cold passband, for stub lengths in the range of interest.

Various degrees of capacitive loading (i.e., addition of ridges or lowering of cavity sidewalls) were used to improve the dispersion characteristic. However, it was found that such improvements are of doubtful value since they also result in a heavy increase in stored energy away from the beam and hence, loss of Pierce impedance (Figs. 5, 6).

The SSM line has a major advantage over competing cylindrical circuits in that its Pierce impedance is insensitive to velocity scaling; for a given stub length, impedance at the circuit depends essentially only on the phase shift between adjacent bars. A theoretical prediction to this extent was readily verified by measurements on two ladder circuits of the Ash type, one having twice the periodic length of the other (Fig. 7). Agreement is well within experimental error.

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[1] J. C. Walling, "Interdigital and Other Slow-Wave Structures," J. Elect. and Contr. 3, 239-258 (1957).

[2] P. N. Butcher, "The Coupling Impedance of Tape Structures," Proc. IEE 104, 177-187 (March 1957).

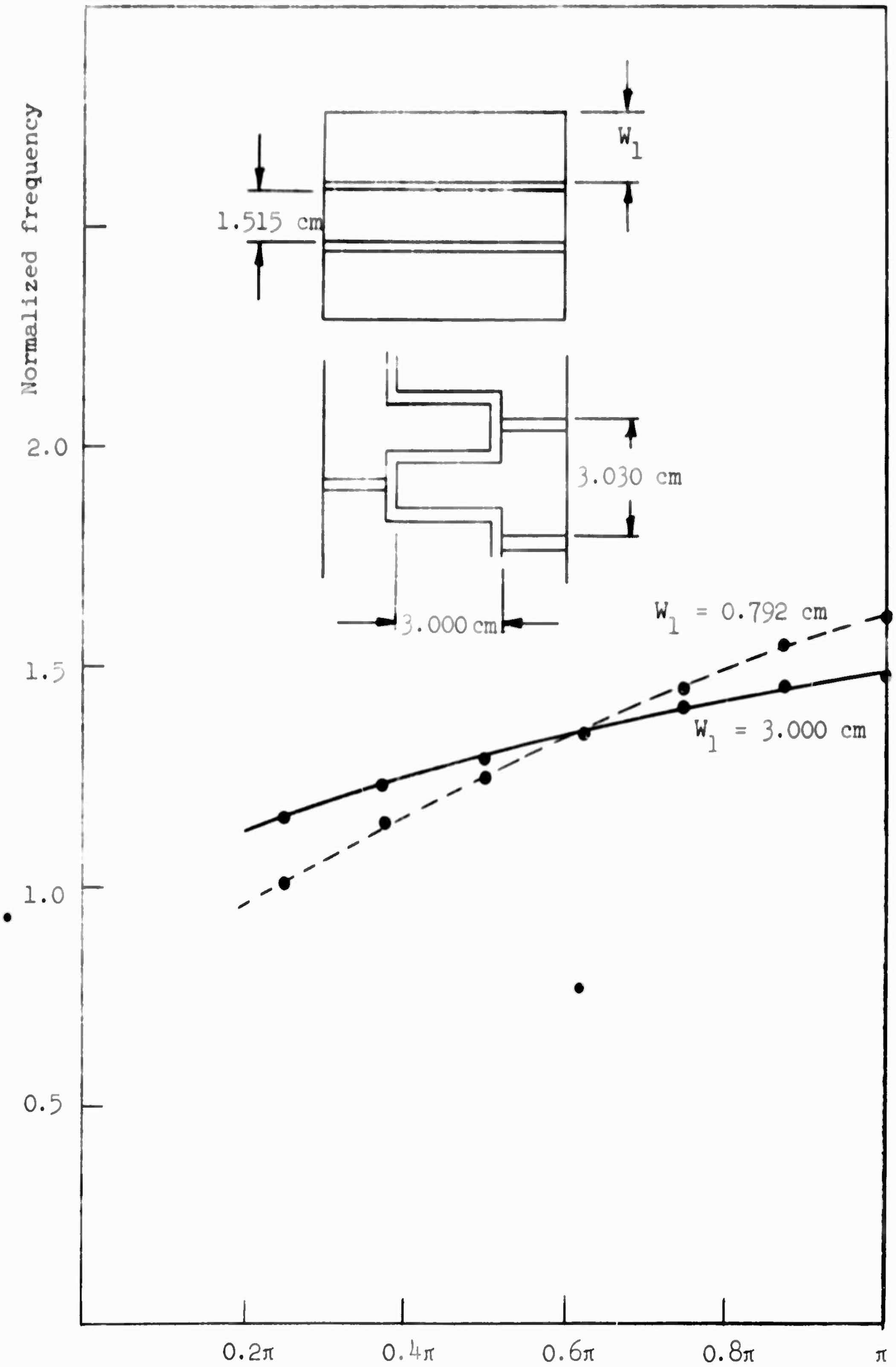

FIG. 5--Double-deck SSM line: effect of changing wall height on dispersion

$$\frac{\text{midsection}}{\text{total width}} = 0.5$$

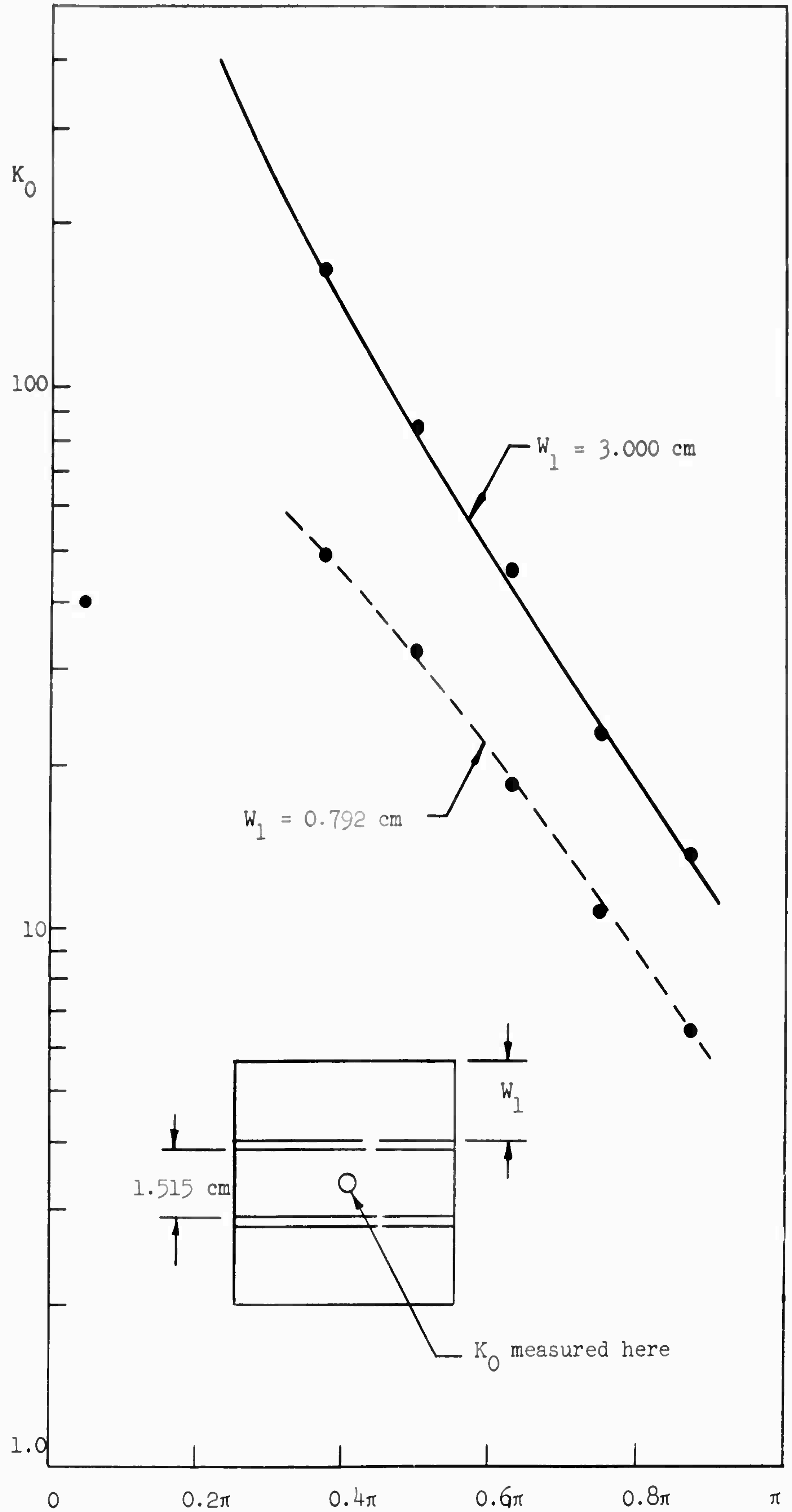

FIG. 6--Double-deck SSM line: effect of changing wall height on Pierce impedance.

$$\frac{\text{midsection}}{\text{total width}} = 0.5$$

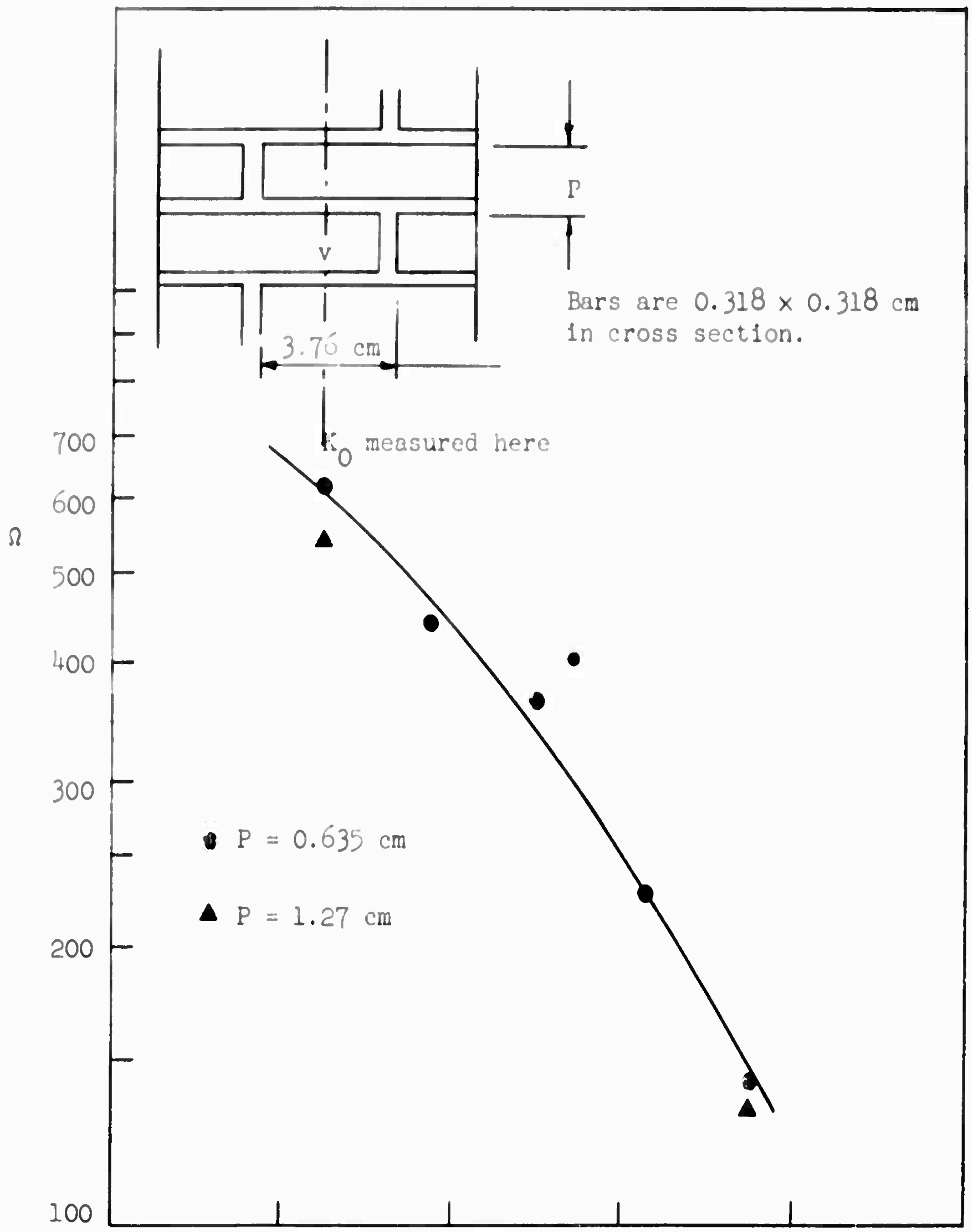

FIG. 7--Ash circuit: effect of velocity change on Pierce impedance grating circuit.

$$\frac{\text{midsection}}{\text{total width}} = 0.5$$

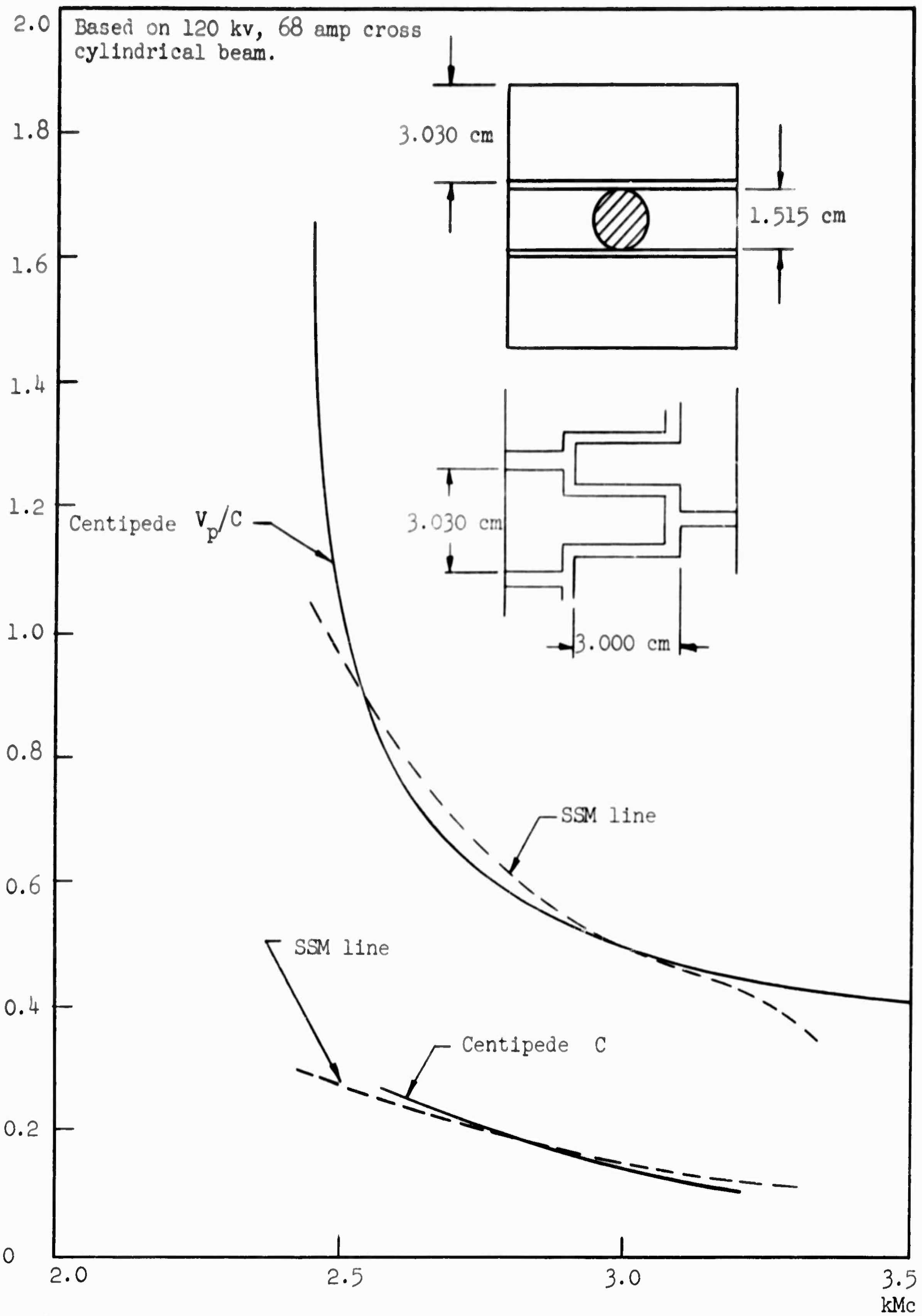

FIG. 8--Pierce gain parameter and dispersion: double-deck SSM line or centipede.

$$\frac{\text{midsection}}{\text{total width}} = 0.4$$

Comparison of scaled measurements made on a double-deck version of the SSM line with results from the centipede circuit,[1] based on a 120 kv cylindrical beam, shows dispersion and Pierce gain parameter to be nearly the same for the two circuits (Fig.8).

An investigation is under way to determine how best to use resonant sections of SSM line as cavities for an extended-interaction klystron. This is concerned principally with the proper choice of interaction length and operating voltage to maximize gain-bandwidth while avoiding oscillation conditions in adjacent cavity modes. A prototype klystron utilizing a double-deck SSM line in four extended-interaction cavities will be built. Beam tests will be conducted using the cylindrical beam provided by the electron stick; results will then be used to estimate performance with a sheet beam.

H. NON-PERIODIC DIELECTRIC-LINED HIGH-POWER TWT (A. Karp)

1. Objective

The main purpose of this project is to demonstrate the feasibility of a pulsed S-band multi-megawatt 80-100 Kv forward-wave amplifier based on a nonperiodic slow-wave structure. This structure will consist of essentially a copper cylinder uniformly lined with beryllium-oxide dielectric. The immediate objective is to test, at low levels, a nonevacuated structure fitting outside the electron stick (described above in section E) in order to verify that the gain, bandwidth, and freedom from parasitic-oscillation tendencies of the dielectric device are as predicted. A subsidiary aim is to explore the possibilities of such nonperiodic dielectric structures as high-voltage millimeter-wave amplifiers or generators.

2. Present Status

The progress of the "Electron Stick" project has been watched so that not all the schemes adopted to control its self-oscillation tendencies will prevent its use in conjunction with a nonperiodic dielectric cylinder. When the length and overall diameter (including a possible outer helix) of the new "stick" are finalized, and the success of self-oscillation control established, a dielectric-cylinder structure will be readied for lowering

---

[1] M. Chodorow, A. F. Pearce, D. K. Winslow, "The Centipede High-Power Traveling-Wave Tube," Microwave Laboratory Report No. 695, Stanford University, (May 1960).

onto the stick. It is at present proposed to have only an input coupler, with the other end of the structure terminated, and the build-up of electronic gain along the length of the device observed with probes. This procedure should expedite the project by initially raising the tolerance on coupler VSWR, among other things.

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